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CSTI High Capacity Power

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CSTI HIGH CAPACITY POWER

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ABSTRACT

The SP-100 program was established in 1983 by DOD, DOE, and NASA as a joint program to develop the technology necessary for space nuclear power systems for military and civil application.

During FY86 and 87, the NASA SP-100 Advanced Technology Program was devised to maintain the momentum of promising technology advancement efforts started during Phase I of SP-100 and to strengthen, in key areas, the chances for successful development and growth capability of space nuclear reactor power systems for future space applications.

In FY88, the Advanced Technology Program was incorporated into NASA's new Civil Space Technology Initiative (CSTI). The CSTI Program was established to provide the foundation for technology development in automation and robotics, information, propulsion, and power. The CSTI High Capacity Power Program builds on the technology efforts of the SP-100 program, incorporates the previous NASA SP-100 Advanced Technology project, and provides a bridge to NASA Project Pathfinder.

The elements of CSTI High Capacity Power development include Conversion Systems, Thermal Management, Power Management, System Diagnostics, and Environmental Interactions. Technology advancement in all areas, including materials, is required to assure the high reliability and 7 to 10 year lifetime demanded for future space nuclear power systems. The overall program will develop and demonstrate the technology base required to provide a wide range of modular power systems as well as allowing mission independence from solar and orbital attitude requirements.

Several recent advancements in CSTI High Capacity power development will be discussed.

INTRODUCTION

As part of the NASA, DOE and DOD SP-100 nuclear space power program, the NASA Advanced Technology Program was devised to maintain the momentum of promising aerospace technology development and to enhance the chances for successful development and growth capability of future space nuclear reactor power systems. In 1988, the Advanced Technology Program was incorporated into NASA's new Civil Space Technology Initiative (CSTI). CSTI is a $900 million, 7 year program intended to start the revitalization of NASA's space technology by means of a focused effort in the areas of transportation, operations, and science. SP-100 advanced technology is now a $65 million, 7 year effort under CSTI Operations called High Capacity Power. The overall goal of this element is to develop the technology base needed to meet the long duration, high capacity power requirements for future NASA Pathfinder space applications such as lunar and planetary bases, high-power-demand electric propulsion systems, and large space platforms.

The funding planned for the remaining 6 years of the program is included in Table 1, which summarizes the funding of each element and lists the totals by element and by year. The FY88 expenditures totalled $12.8 million, of which $10 million was for GES support. SDIO has contributed approximately $500,000/year to the advanced technology work from FY86 through 89. Present plans show $1 million/year from SDIO for SP-100 advanced technology in FY90, 91 and 92.

CSTI HIGH CAPACITY POWER

The High Capacity Power program will focus on the development of key aerospace technology in the areas of Energy Conversion, Advanced Materials, Thermal Management, Power Management, System Diagnostics and Environmental Interactions. Program Management is located in the Office of Aeronautics and Space Technology (OAST) at NASA Headquarters. Project Management is located at NASA Lewis Research Center in the Power Technology Division of the Aerospace Technology Directorate. The advanced thermoelectric energy conversion element is carried out at Jet Propulsion Laboratory in Pasadena, California.

A Systems Analysis and Missions Support element is used to assess the benefits from technology advancements in all areas, and to show how new technology impacts future NASA missions. Figure 1 illustrates the goal of the High Capacity Power project in terms of increased power as well as higher specific power available from the GES reactor when all technology goals are met.

The overall project roadmap is shown on Fig. 2. The timing was originally intended to ensure that significantly enhanced technology options would be available by the mid 1990's, when the SP-100 Ground Engineering System (GES) reactor and aerospace technology elements were scheduled for demonstration at the 100 kWe scale.

Advanced thermoelectric development could double the specific power available from the GES reactor. Advanced Stirling development with concommitant gains in all areas, could provide a factor of 5 to 6 increase in power from the GES/ reactor. These relationships and the technology goals are given in detail on Fig. 3 for comparison with the original curve of Fig. 1. The funding peaks for both CSTI and GES have been reduced, both programs have been stretched from 5 years originally to 7 years now, with further stretchouts likely as reprogramming is accomplished and as problems arise in the success-oriented plans. The overall roadmap of Fig. 2 assumes continued funding of critical development areas beyond the presently planned cutoff in FY94.

ADVANCED POWER CONVERSION

Advanced power conversion development is intended to provide options to the SP-100 GES Program for growth to higher power levels, increased efficiency, higher reliability, longer life, or effective full capability operation at lower reactor temperatures. Free-piston Stirling dynamic power conversion will be pursued for its high performance capability and thermoelectric static power conversion will be pursued for its ease of integration with GES and its inherent graceful degradation characteristics.

STIRLING

The Stirling development program will expand on the technology developed during Phase I and will proceed with the development of common design 1050 and 1300 K Stirling power converters. Schematics showing the integration of these converters with the GES reactor are given on Figs. 4 and 5. Stirling technology includes heat input, heat removal through the cooler, and control of the converter through appropriate power conditioning development to provide acceptable electric power to a range of user applications.

The Stirling development program is illustrated pictorially on Fig. 6. The 650 K Space Power Demonstration Engine results are presented in Refs. 1 through 5. Component development in the areas of bearings, regenerators, heat pipe heat input, loss reduction and understanding, and temperature increases will be performed at the 12.5 kWe size. When the appropriate technology gains have been demonstrated, they will be incorporated into the 1050 K superalloy Space Stirling Engine (SSE) at 25 kWe to be tested by the end of FY92. The design goals for this power converter are given in Table 2. A design approach to meeting these goals in a single cylinder, internally balanced concept is shown in Fig. 7. The component technologies advancing to 1300 and 650 K (cold end) will also be accomplished in parallel, leading to the refractory Stirling Space Engine demonstration by the end of FY97, assuming funding continues beyond the current end date of FY94.

Key technology developments in FPSE technology already accomplished include the following:

(1) Demonstration of heat pipe heat input to a FPSE at 975 K - see Fig. 8. The modules, each designed to deliver 2 kW of power to the FPSE, are of the size and configuration such that 40 modules would supply the 25 kWe SSE at 1050 K.

(2) Demonstration of an electrically spun hydrodynamic bearing applied to the power piston of the SPRE (1/2 of the SPDE). The bearing performed satisfactorily with low power (700 W) requirement while reciprocating 20 mm at 103 Hz and rotating at 730 r/min.

(3) Demonstration of an 87 percent efficient linear alternator by means of material substitution and configuration changes to enhance the efficiency from the 70 percent value originally measured .

The next step in the evolution toward the 25 kWe 1050 K SSE is to develop the 525 K cold end components and demonstrate them at 12.5 kWe size in an operating FPSE.

THERMOELECTRICS

The potential for significant improvement in the figure of merit (Z) of Si-Ge alloys has been observed under SP-100 advanced technology work. The improvement for n-type material is illustrated on Fig. 9, for GaP additive to Si-Ge. Exploitation of this breakthrough requires understanding of the microstructure of the improved materials (see Fig. 10), and how to optimize the constituents/ microstructure while controlling the process for reproducibility.

Based on the increased understanding gained during the past year, a three-pronged approach is being taken. Si-Ge crystals will be grown at JPL using various fabrication techniques (vibrational stirring, zone-leveling and liquid phase epitaxy). These samples will be free of the defects inherent in hot-pressed samples (oxygen, grain boundaries, etc.) making an investigation of each of the several variables (dopants, dopant concentration and composition) by itself possible. A theoretical model of both the electrical and thermal properties will be developed at JPL to further increase the understanding of the improvement so that it can be optimized. Work on hot-pressed samples will be continued at the contractors (funded by SP-100 and Pathfinder) and the close interaction between them and JPL maintained so that advances and technology can be transferred easily. University expertise will be enlisted through contract to assist with the theoretical understanding. The improved understanding will be applied to the p-type material such that a combined $Z = 1.4$ can be demonstrated by FY93 for application to multicouples in FY94.

ADVANCED MATERIALS

Materials development is critical to the success of all advanced space power systems, A broad-based program underway at NASA Lewis is summarized on Fig. 11. PWC-11 material exhibits the strength advantage over Nb-1Zr (the SP-100 GES material) illustrated on Fig. 12. Even after welding and aging, significant strength advantages remain, as shown in Fig. 13.

A 75 kg heat of PWC-11 (Nb-1Zr-0.1C) has been purchased from Teledyne Wah Chang. ORNL has extruded the billets at 1900 K and is fabricating 1 mm sheet for creep testing. Creep tests already underway for over 20 000 hr at 1350 K, 10 MPa have shown no indication of strain to date. The strengthening precipitate in PWC-11 has been identified as a 70Zr-30Nb monocarbide.

Refractory fiber reinforced composites show a further improvement in stress-to-density ratio at 1500 K as given on Fig. 14. Further work is planned to complete densification of the matrix by optimization of the hot pressing parameters. Fiber-matrix interface examination indicates that Nb-1Zr is more reactive with W alloy fibers than is Nb. Further tests on wire/matrix stability and strength will be followed by fabrication development and application of the advanced materials to structures such as Stirling pressure vessels or fluid transport ducts/manifolds for 1400 to 1500 K service.

Graphite copper composites, manufactured by the same techniques at NASA Lewis, are being developed for space radiator applications. The configuration and advantages over beryllium or copper are depicted on Fig. 15. When the best fibers have been determined, methods for attaching heat pipes will be developed and tests of radiator segments will be performed.

THERMAL MANAGEMENT

The goal of the thermal management effort is to develop space radiator concepts optimized for both static and dynamic power systems using nuclear heat sources. Specific goals include 5 kg/m^2 specific mass, survivability up to 10 years in the micrometeoroid and space debris environment, and 0.99 reliability.

Advanced radiator concept contracts are presently underway to meet these goals at 875 K for the thermoelectric system and at 600 K for the Stirling system. The contracts are presently in Phase III - a demonstration of the resolution of feasibility issues at the components level. Space Power Inc. is working on an 875 K heat pipe radiator as well as a pumped loop design for the 600 K concept. Rocketdyne is working on carbon-carbon composite heat pipes integrated with a carbon-carbon fin structure. The plan is to proceed through Phase IV where subsystem testing will demonstrate engineering performance of these concepts by the end of FY91.

A significant effort at NASA Lewis is the enhancement of radiator surface emissivity through surface morphology changes. Techniques used include chemical etching, abrasion, sputter texturing, electrochemical etching, arc texturing, and combinations of these. It has been found that all radiator materials of interest (except beryllium) for SP-100 application can be treated sufficiently to meet the 0.85 emissivity requirement. Figure 16 shows the changes in Nb-1Zr under the various surface treatments listed. Carbon-carbon composites have been enhanced significantly in emissivity by exposure to atomic oxygen in the laboratory.

Plans for FY89 include construction of a high temperature vacuum spectral emissometer which will allow spectral emittance measurement with the specimen at the operating radiator temperature. Durability of treated surfaces will be determined to assure that the emissivity remains high for the projected 7 year lifetimes.

Theoretical code development for heat pipe design and performance as well as radiator performance are also under development at NASA Lewis and through university grants. The goal is to understand and predict radiator behavior under transient as well as steady state operation.

To better correlate the theoretical models, a heat pipe laboratory is being constructed at NASA Lewis to allow test and detailed measurement of heat pipe/radiator characteristics under simulated space operating conditions. Initial tests underway during FY89 will concentrate on development of experimental tools and equipment applied to water heat pipes.

POWER MANAGEMENT

Power management is the conditioning and control of unregulated power from the power conversion subsystem via a transmission line to a regulated spacecraft power bus for distribution to the required loads. The results of task one under this effort were published in Refs. 6 to 8. Power circuits demonstrated included a 100 VDC, 2.5 kW, 20 kHz distribution system driven by a cascaded Schwarz converter and a 100 VDC, 2.5 kW, 20 kHz phase controlled, parallel-loaded converter. Present plans include development of the power conditioning, control and transmission (PCC&T) subsystem for a free-piston Stirling engine/linear alternator conversion system such that mass, efficiency and stability of the entire system delivering power to a user is optimized.

A second task is to determine the survivability and operating characteristics of solid state semiconductor switches under combined neutron and gamma irradiation simulating 7 to 10 year missions with the SP-100 nuclear reactor. Commercial transistors tested to the SP-100 7-year radiation specifications exhibited a large reduction in current gain, a large reduction in switching storage time, a decrease in breakdown voltage for fixed leakage current, and a small improvement in rise and fall switching times. Reference 9 describes these results in detail.

Plans are to measure the combined effects of temperature and neutron and gamma irradiation on a range of solid-state switches. In addition, effects of post-irradiation thermal annealing over a range of temperatures will be determined. High power switches to be investigated include Bipolar Junction Transistors (BJT), power Metal-Oxide-Semiconductor Field Effect Transistors (MOSFET), Insulated Gate Transistors (IGT) Static Induction Transistors (SIT), Thyristors or Semiconductor Controlled Rectifiers (SCR), and Metal-Oxide-Semiconductor Controlled Thyristors (MCT).

The third task concerns temperature, frequency and radiation effects on soft magnetic materials. The use of such materials in transformers, inductors, motors, generators, and TEM pumps under high frequency excitation and high temperature/radiation environments, requires knowledge of magnetic properties and loss mechanisms in order to design proper PCC&T systems. Present plans are to report the NASA Lewis experimental results on two iron-based alloys and one 80:20 Ni-Fe alloy tested to 50 kHz and 250 °C. Further work will evaluate 50:50 Ni-Fe, 3 percent Si-Fe, 6 percent Si-Fe, 27 percent Co-Fe under sinusoidal and nonsinusoidal voltage excitation over a range of 400 Hz to 20 kHz for temperatures up to 300 °C.

SYSTEM DIAGNOSTICS

Spacecraft now in orbit are prone to problems caused by static charge buildup and discharge. Future launch vehicles using electromechanical actuators will require high power levels which will be more prone to electromagnetic interference generation. Space power systems require electrical current sensors which are immune to electromagnetic interference and static charge effects. Fiber optic current sensors fill both requirements. They are also lightweight and can be placed at reasonable distances from central electronics. Other diagnostic sensors need to contain signal processing abilities so that only processed information is passed to executive level computers, saving the executive level computers from the overburden of processing which can be done locally at the sensors. The earlier phases of this project concentrate on fiber optic current sensor development and on the development of smart sensors, while the latter phases are more concerned with development of diagnostics at the system level.

The National Institute of Standards and Technology (formerly the National Bureau of Standards) is under contract to NASA Lewis to develop electrical current sensors which are fiber optic sensing components (via the Faraday Effect). The ac sensors will be broadbanded (covering 30 Hz to 1 MHz), and are being designed specifically to withstand aerospace vibration and temperatures. Two versions are called for: 10 A full scale and 200 A full scale. Target accuracy is 1 percent full scale.

SPACECRAFT ENVIRONMENTAL EFFECTS

The near earth space environment subjects spacecraft to oxygen attack, which is directional as well as material specific; in addition, possible space plasma interactions with power cabling could induce insulation breakdown and shorting of the power system. Initial studies focus on the environment at a low Earth orbit of 500 km. The various effects are illustrated on Fig. 17. Space systems of the future will be larger, longer-lived and higher-powered. They must operate predictably and reliably in their total space environment, and be compatible with users (e.g., scientific experiments). Systems involving nuclear power generation in the 100 kW to MW range, coupled with high capacity power conversion and distribution schemes and electric propulsion, are prime candidates for serving the high power needs in space for the future. The large sizes and high power levels envisioned for these systems ensure that they will interact strongly with the plasma and field environments, both natural and system-generated, and the high voltages anticipated for high power systems may also induce electrical breakdown of neutral gases. Electric thrusters will generate neutral and low energy plasmas as well as the primary beam, which will contribute significantly to the local environment. The passage of the Space Shuttle through the ionosphere is known to create significant plasma turbulence. The scaling of such turbulence with system size, and the coupling between high power ac and dc distribution systems and environmental plasmas may be significant.

To ensure predictable performance and extended lifetime of high power ac and dc systems requires development of predictive models of the local environments around them and the effects of interactions with these environments on the systems. This program will provide the required models in the form of user-friendly computer codes, and will employ the models to identify and evaluate design strategies and technology advances to eliminate mission threats due to environmental interactions effects. Theory and model development along with ground-based experimentation are included in the program. Data from existing flight experiments will be used to the extent possible to validate the models. Additional critical flight experiments will be recommended.

In addition to the foregoing studies on the near earth space environment, similar studies must be made on lunar and planetary environments, particularly the Martian atmosphere and the lunar and Martian dust.

The atomic oxygen ion beam facility at Case Western Reserve University was improved by the addition of a new electron gun sample heater. Using the new capabilities, the investigators at CWRU, under grant to NASA Lewis, obtained reaction efflux rate data, at high atomic oxygen energies and high sample temperatures, from the two SP-100 materials, Mo and Nb-1Zr. Neither material showed a significant loss of any volatile oxidation products, indicating that mass loss due to atomic oxygen exposure in orbit would be minimal. Of course, embrittlement or other material damage due to oxygen diffusion into the materials could not be detected by this experiment.

S-cubed Corp., under contract to NASA Lewis, performed the first computer analyses of SP-100 power systems interactions with the space plasma. Runs of NASCAP/LEO and the POLAR codes were done, using a dummy payload configuration, to see how the SP-100 configuration would collect current from the plasma, and what potentials would be generated. It was found that the User Interface Module (UIM) joint between the power system and the payload was a possible location for high potential gradients to form, leading to an increased possibility of arcing into the plasma and to other parts of the spacecraft. This is due primarily to the specific grounding scheme being considered for the SP-100 spacecraft, with the power system structures effectively biased 100 V relative to the payload structure ground. Further work is underway to develop mitigation strategies for this potential problem.

The NASA Lewis in-house atomic oxygen beam facility to test material important to the SP-100 program will be brought into operation. Initial testing will confirm previous results on Kapton, and allow calibration of the fluxes and energies of the beam. Further investigations will involve SP-100 materials, such as refractory metals, radiator materials, cabling materials, etc. Oxygen plasma testing of important materials, such as cables and biased exposed conductors, will take place in the same vacuum chamber. A collaborative arrangement with Langley may result in testing and evaluation of many other materials, including those which may be used for the electrodynamic tether. Transport of exposed samples, still in vacuo, will be attempted to the facilities at Langley, for exhaustive surface analysis and chemical interpretation.

Samples of SP-100 materials will be readied for the Effects of Oxygen Interactions on Materials (EOIM-3) experiment, set to fly on STS-44 in January, 1991. As samples must be delivered to the Cape by mid-1990, the samples must be fabricated or acquired, and final decisions as to which samples to include must be made in 1989. The EOIM-3 experiment is summarized on Fig. 18.

SUMMARY

The NASA CSTI High Capacity Power Program is a broad based effort to provide significant improvements in the technology associated with space nuclear power and its relationship with the space environment. The inherent advantages of space nuclear reactor power - compactness, low mass, long life, and reliability - must be coupled with aerospace technology which can capitalize on these advantages. CSTI High Capacity Power supports and advances all the non-nuclear aspects of the SP-100 GES reference flight system (RFS) design and some of the materials research could provide significant design margin to the reactor. The focused nature of the program will insure that the technology advances are in place by the mid-1990's so that NASA's long-term goals in civil space exploration and exploitation may be achieved.

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TABLE 1. - CSTI HIGH CAPACITY POWER ESTIMATED FUNDING SUMMARY, MILLION DOLLARS

	FY89	FY90	FY91	FY92	FY93	FY94	6 Year total
1.0 Project management	0.100	0.100	0.100	0.100	0.400	0.040	0.480
2.0 Systems analysis and missions support	.100	.100	.100	.100	.060	.060	.520
3.0 Conversion systems							
3.1 Advanced stirling	5.500	5.400	5.909	5.698	2.415	2.450	27.372
3.2 Advanced thermoelectrics (JPL)	.800	.700	.400	.400	.100	.100	2.500
4.0 Advanced materials	.500	.500	.500	.500	.100	.100	2.200
5.0 Thermal management	2.000	1.900	2.000	1.900	.100	.100	8.000
6.0 Power management	.287	.267	.300	.200	.100	.100	1.254
7.0 Systems diagnostics	.097	.100	.100	.100	.020	.020	.437
8.0 Environmental interactions	.175	.175	.175	.125	.025	.025	.700
Net R&D dollars	9.559	9.242	9.584	9.123	2.960	2.995	43.463
Central scientific and technical ADP	.737	.766	.797	.829	.862	.896	4.887
W/T technical facilities	.665	.692	.719	.748	.778	.809	4.411
Gross	10.961	10.700	11.100	10.700	4.600	4.700	52.761

TABLE 2. - 1050 K STIRLING SPACE ENGINE GOALS AND SPECIFICATIONS

End of life power, kWe	25
Efficiency, percent	>25
Life, hr	60,000
Hot side interface	Heat pipe
Heater temperature, K	1050
Cooler temperature, K	525
Vibration - casing peak-peak, mm	<0.04
Bearings	Gas
Specific mass, kg/kWe	6.0
Frequency, Hz	70
Pressure, MPa	15.0

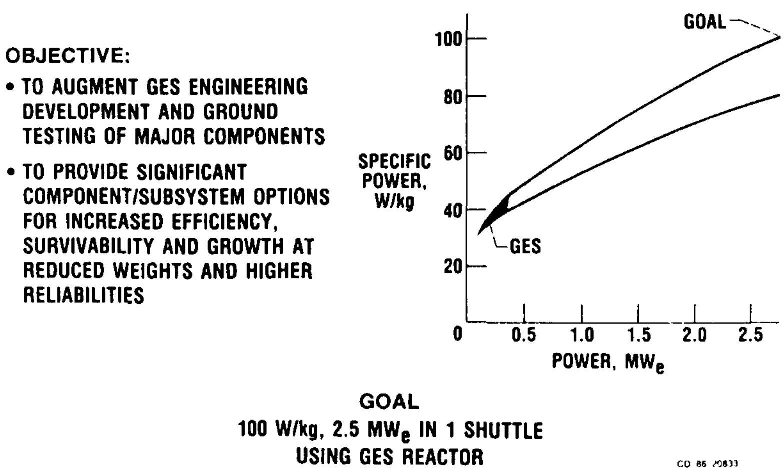

FIGURE 1. - NASA SP-100 ADVANCED TECHNOLOGY PROGRAM.

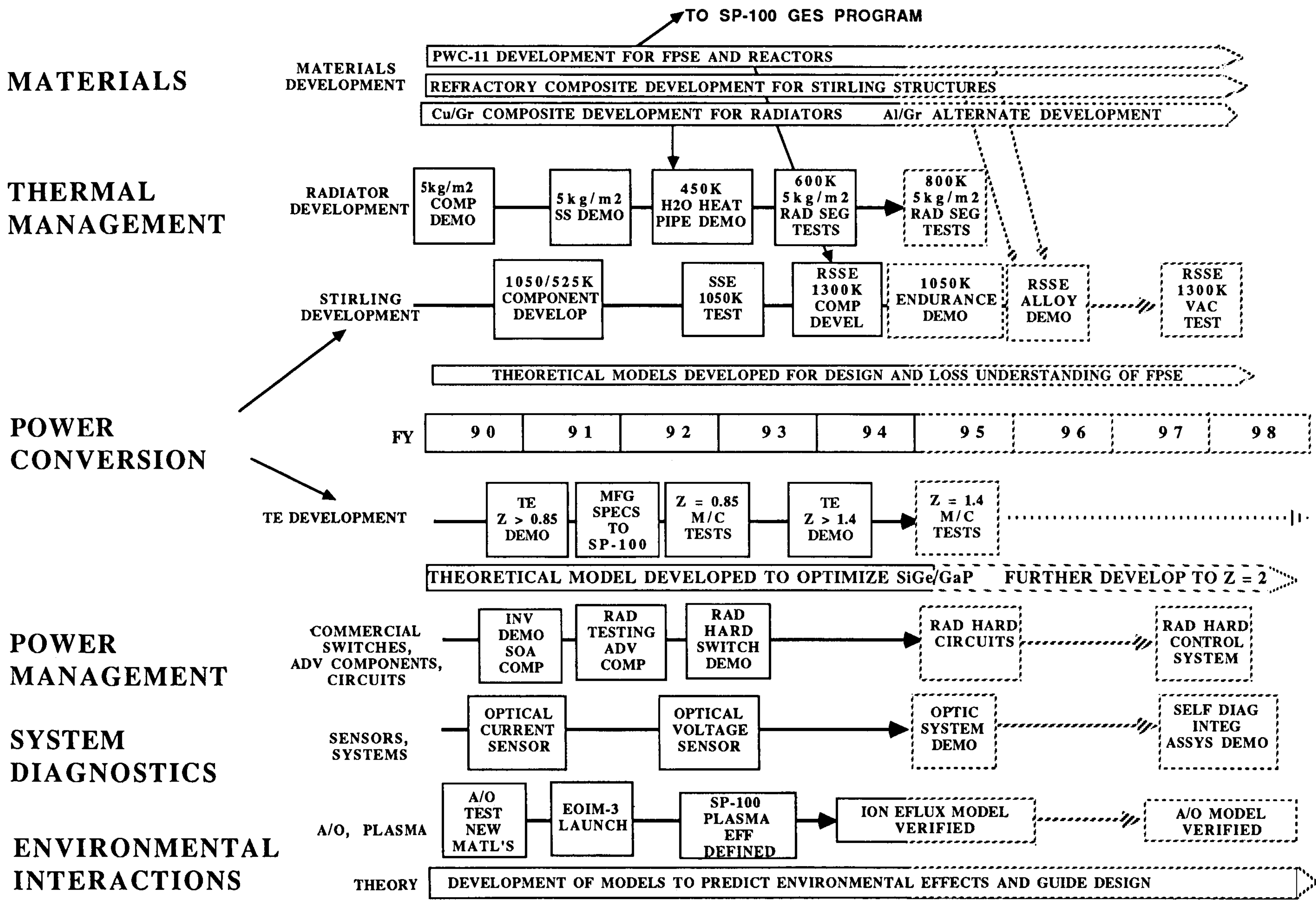

FIGURE 2. - TECHNOLOGY PLAN.

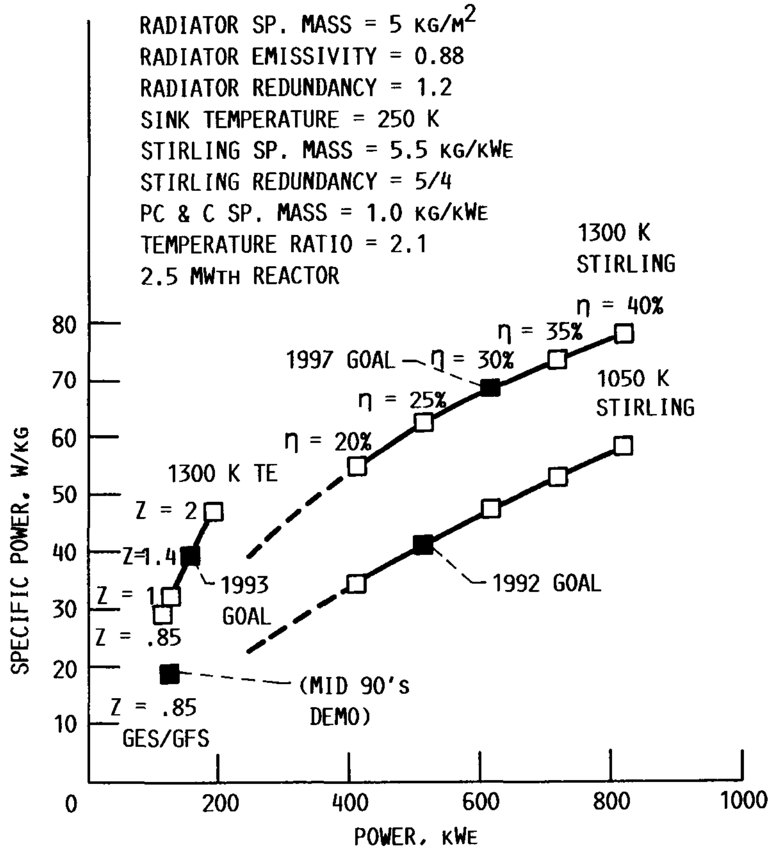

FIGURE 3. - EXTENDING SP-100 REACTOR POWER SYSTEMS CAPABILITY.

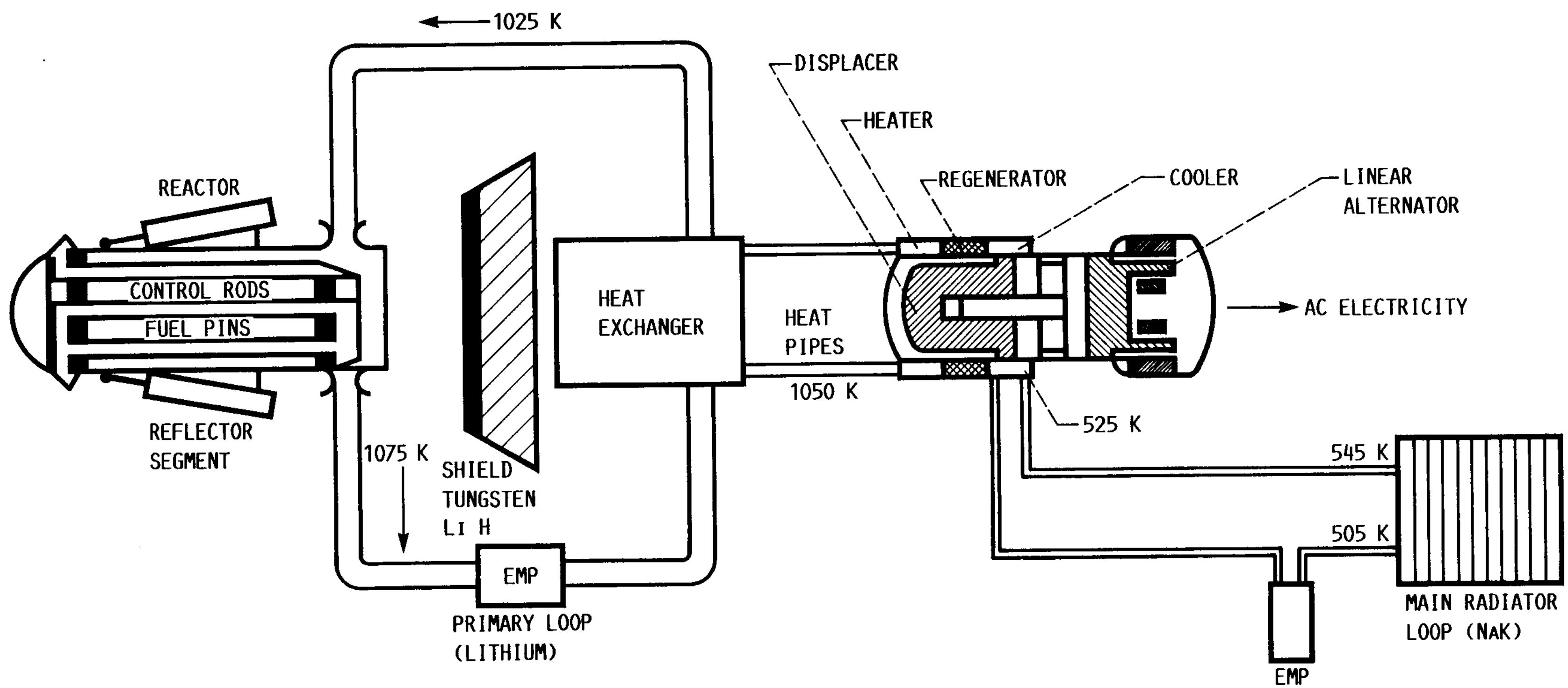

FIGURE 4. - SP-100 SYSTEM SCHEMATIC, STIRLING CYCLE, SUPERALLOY.

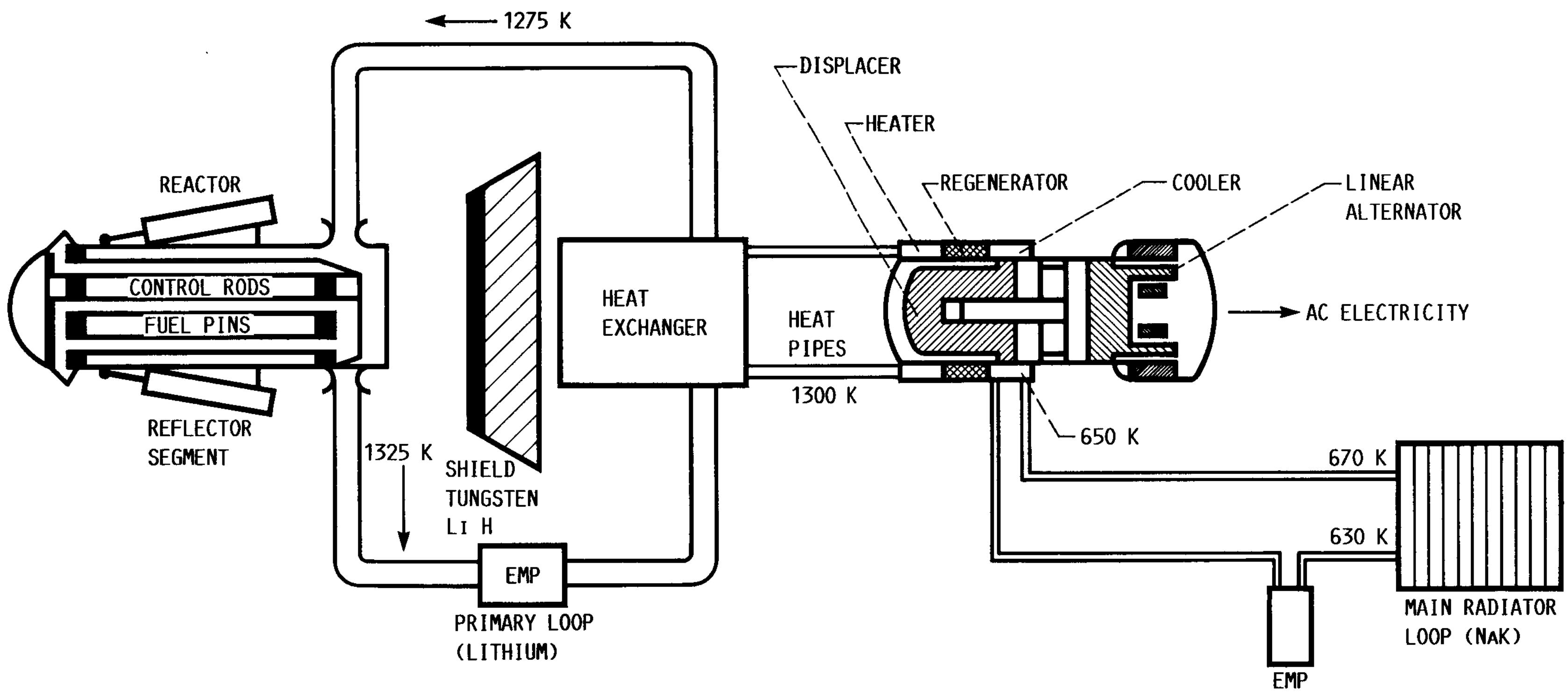

FIGURE 5. - SP-100 SYSTEM SCHEMATIC, STIRLING CYCLE REFRACTORY.

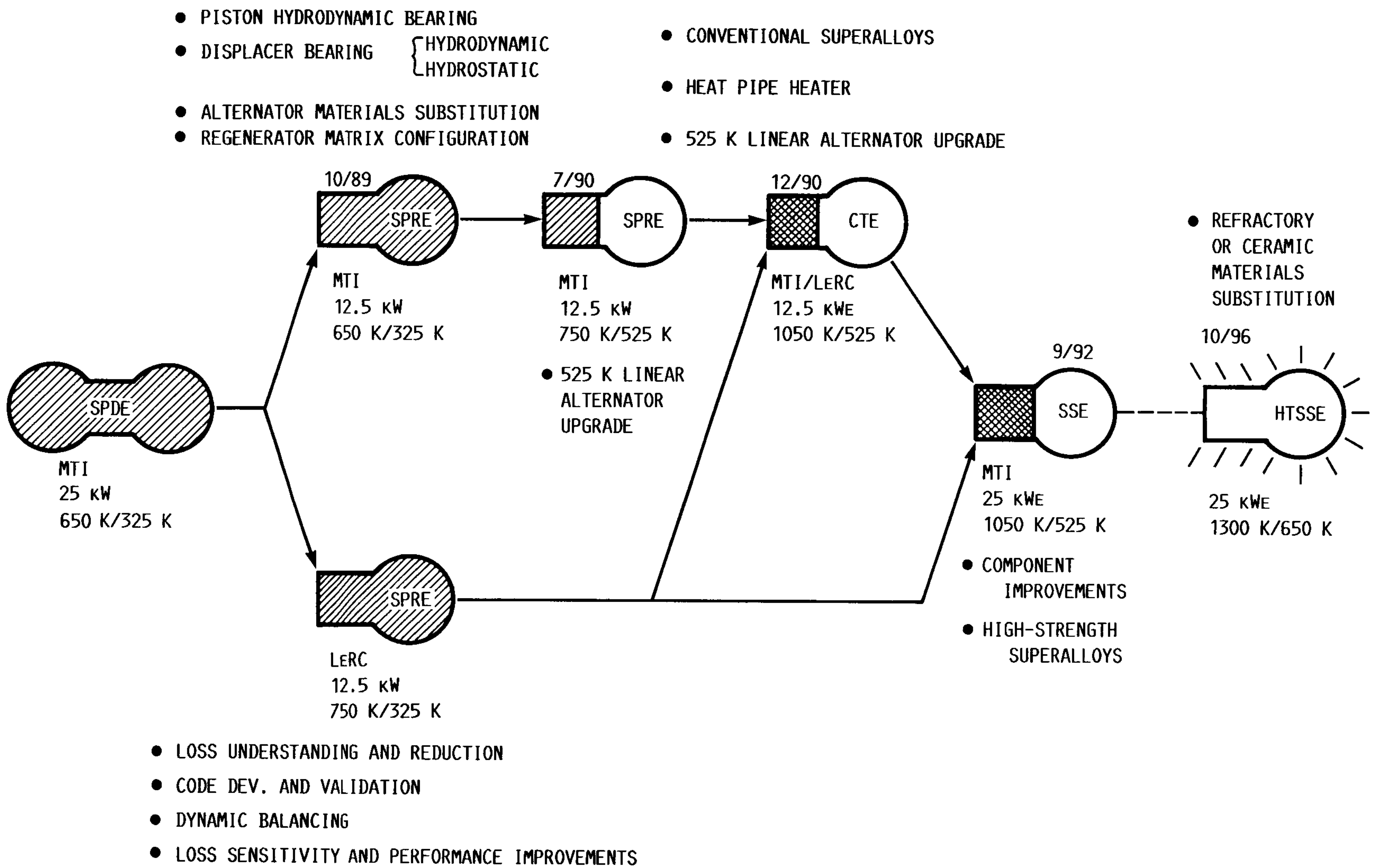

FIGURE 6. - EVOLUTION OF A HIGH TEMPERATURE (1300 K) STIRLING SPACE ENGINE.

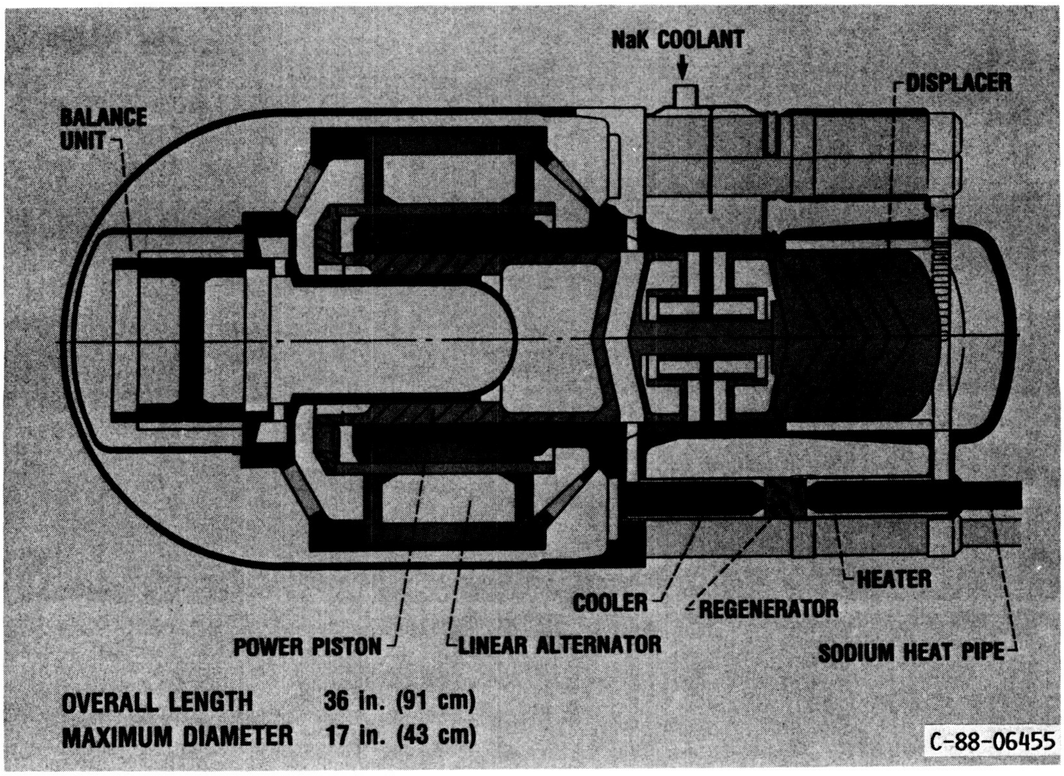

FIGURE 7. - SUPERALLOY STIRLING SPACE ENGINE, SSE.

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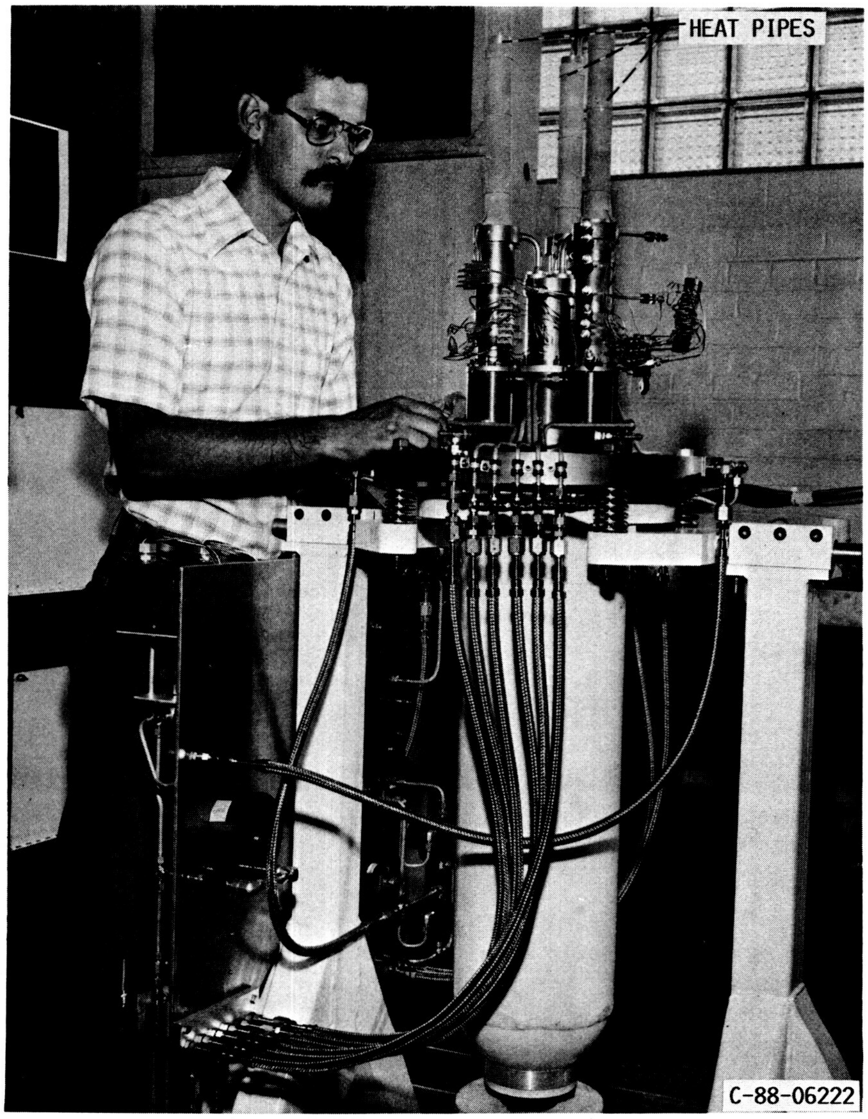

FIGURE 8. - FPSE WITH HEAT PIPE HEATER HEAD.

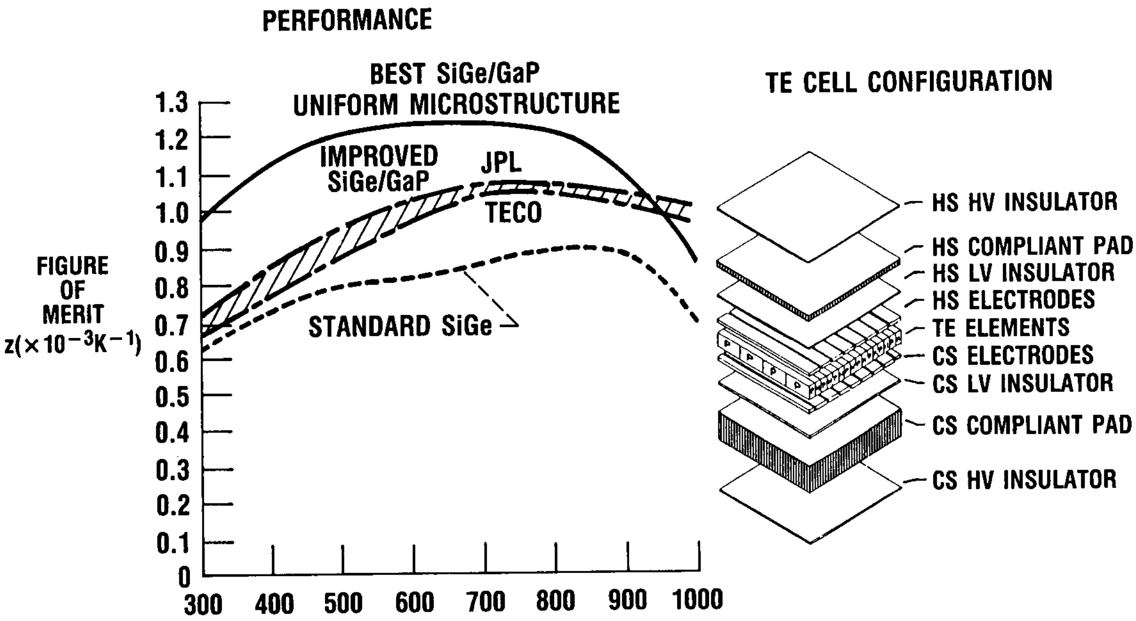

FIGURE 9. - CSTI ADVANCED THERMOELECTRICS. CD-88-34369

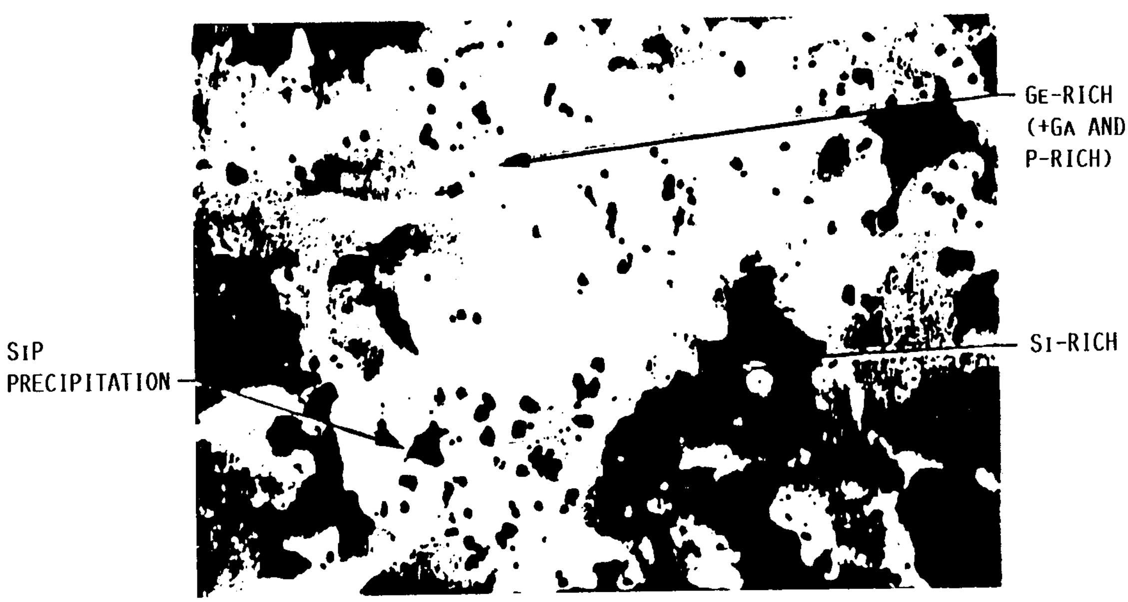

FIGURE 10. - HIGH TEMPERATURE HEAT-TREATMENT (1275-1320 ^{0}C) RESULTS IN VARIOUS PHASES (SI-RICH, GE, GA, P-RICH AND SIP) WHICH PRODUCE THE IMPROVEMENT, MICROSTRUCTURE OF IMPROVED SIGE/GAP.

ADVANCED TECHNOLOGY

- **TUNGSTEN/NIOBIUM COMPOSITES**
  HEAT PIPES & REACTOR STRUCTURES
  - COMPOSITE FABRICATION DEVELOPED
  - SIGNIFICANT IMPROVEMENT IN UTS OVER Nb-1Zr AT 1255 TO 1477 K
    6 TO 11 FOLD IMPROVEMENT IN UTS
    4 TO 8 FOLD IMPROVEMENT IN UTS/DENSITY
  - ONGOING CREEP TESTS SHOW SIMILAR IMPROVEMENTS

- **GRAPHITE/COPPER COMPOSITES**
  RADIATOR PANELS
  - HIGH THERMAL CONDUCTIVITY MATERIAL TO REPLACE BERYLLIUM
    POTENTIAL MASS SAVINGS
    ELIMINATE TOXICITY PROBLEMS

- **THERMOELECTRIC MATERIALS CHARACTERIZATION**
  ENERGY CONVERSION
  - $LaS_{1.4}/GaP$ DOPED SiGe
  - MICROSTRUCTURAL ANALYSIS UNDERWAY
  - TENSILE STRENGTH CHARACTERIZATION UNDERWAY

GES SUPPORT

- **HIGH VACUUM CREEP TESTS OF Nb-1Zr AND PWC-11**
  HEAT PIPES & REACTOR STRUCTURES
  TESTED IN STANDARD DOUBLE ANNEAL CONDITION TO DETERMINE INITIAL PROPERTIES
  - TESTED AFTER 1000-HOUR AGING AT 1350 K TO SIMULATE POSSIBLE SERVICE CONDITION
  - PWC-11 INDICATES 150 K ADVANTAGE OVER Nb-1Zr AT DESIGN STRESS

- **CREEP TESTING OF PWC-11 AT 1350 K**
  JOINING TECHNOLOGY
  - DETERMINE EFFECT OF HEAT TREATMENT ON WELDMENTS
  - MATERIAL FAILS IN BASE-METAL AREA
  - PWC-11 EXHIBITS 2.5 FOLD INCREASE IN STRENGTH OVER Nb-1Zr AT 7 YEAR DESIGN TIME

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FIGURE 11. - MATERIALS FOR SPACE POWER SYSTEMS.

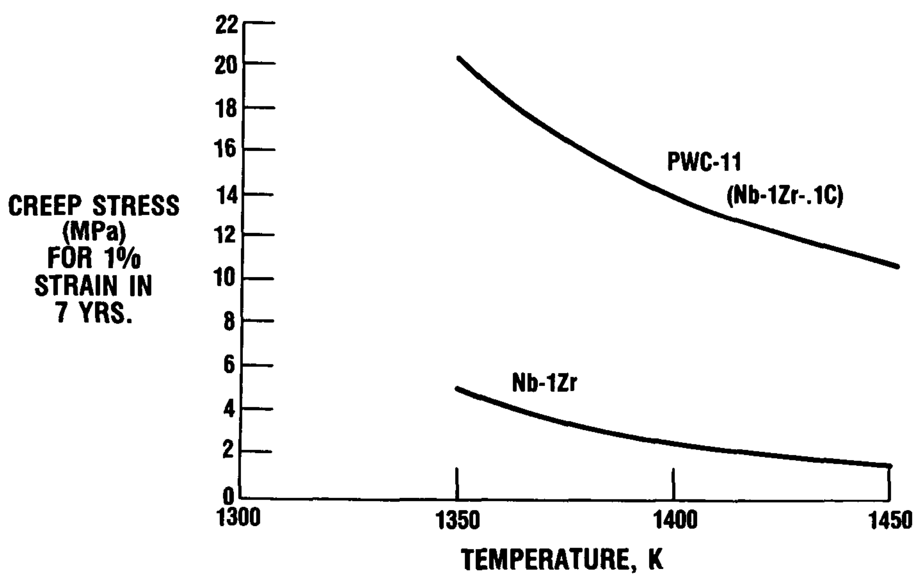

FIGURE 12. - PWC-11 ALLOY EXCEEDS THE DESIGN REQUIREMENTS FOR SP-100 NUCLEAR SPACE POWER SYSTEMS.

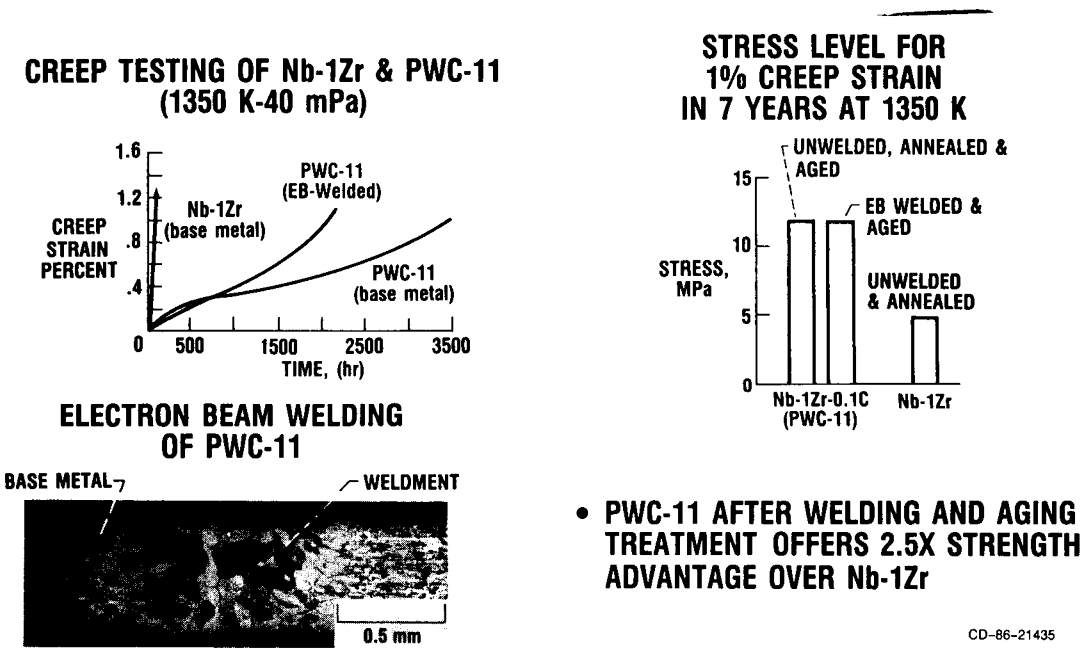

FIGURE 13. - MATERIALS FOR SPACE POWER SYSTEMS GES SUPPORT.

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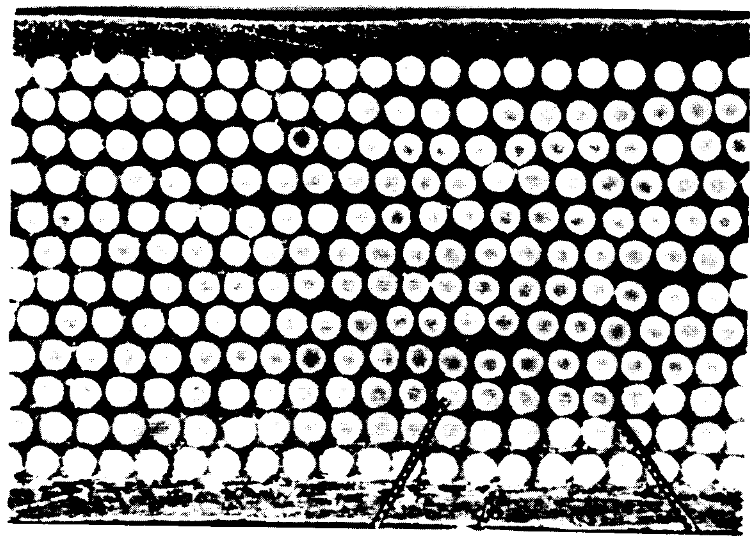

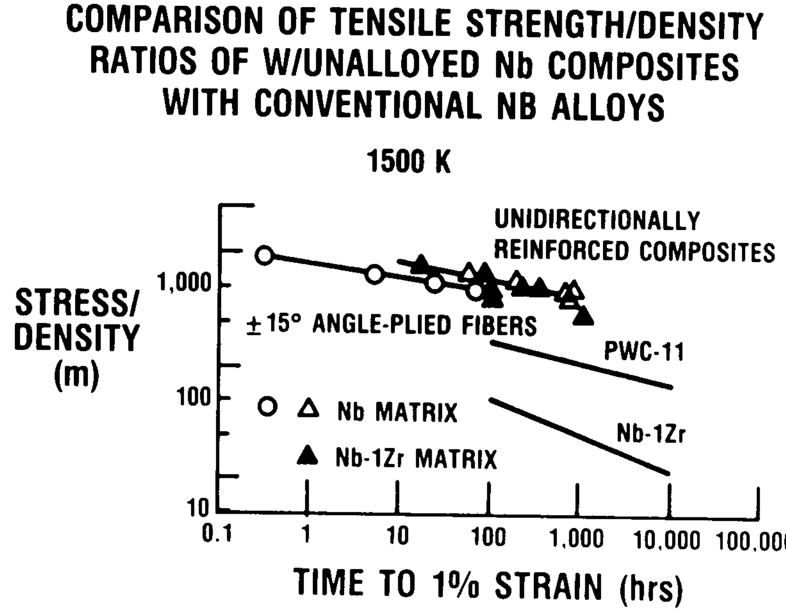

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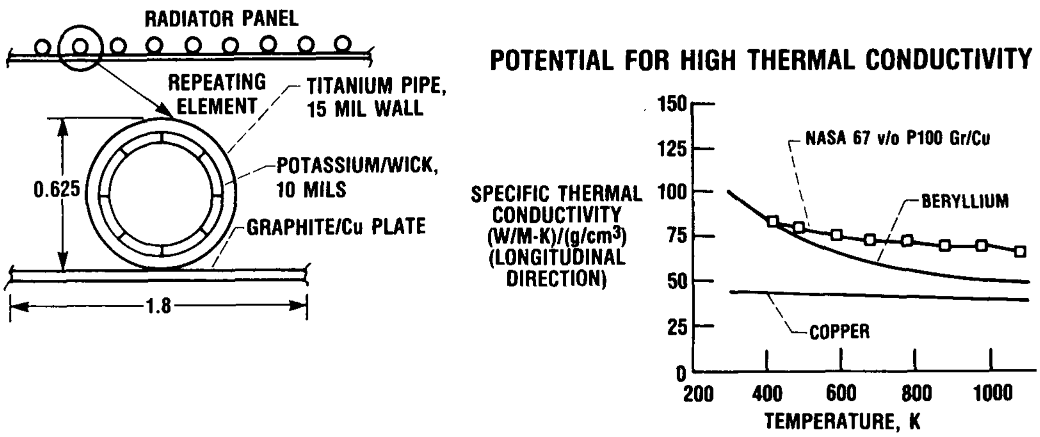
FIGURE 14. - TUNGSTEN FIBER REINFORCED NIOBIUM MATRIX COMPOSITES FOR SPACE POWER APPLICATIONS. FABRICATED USING ARC-SPRAY PROCESS INVENTED AT NASA-LEWIS RESEARCH CENTER.



DESIGN CONSIDERATIONS

- FUNDAMENTAL FREQUENCY > 100 Hz (HIGH MODULUS/DENSITY)
- THERMAL EXPANSION MATCHES Ti HEAT PIPE (TAILORED CTE)
- THERMAL CONDUCTANCE PERPENDICULAR TO HEAT PIPE MATCHES Be (HIGH THERMAL CONDUCTIVITY)
- WEIGHT EQUIVALENT TO Be (LOW DENSITY/DESIGN COMPENSATION)

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FIGURE 15. - GRAPHITE-COPPER COMPOSITES FOR ADVANCED RADIATORS.

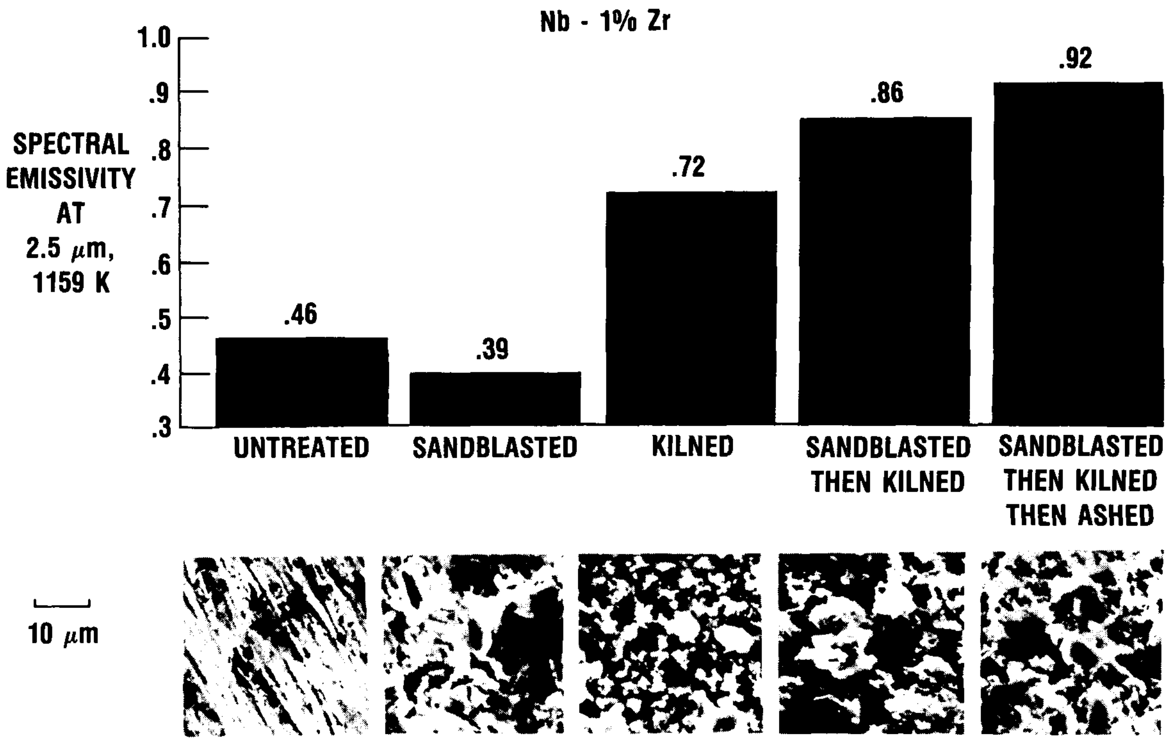

FIGURE 16. - RADIATOR SURFACE MODIFICATION FOR HIGH EMISSIVITY.

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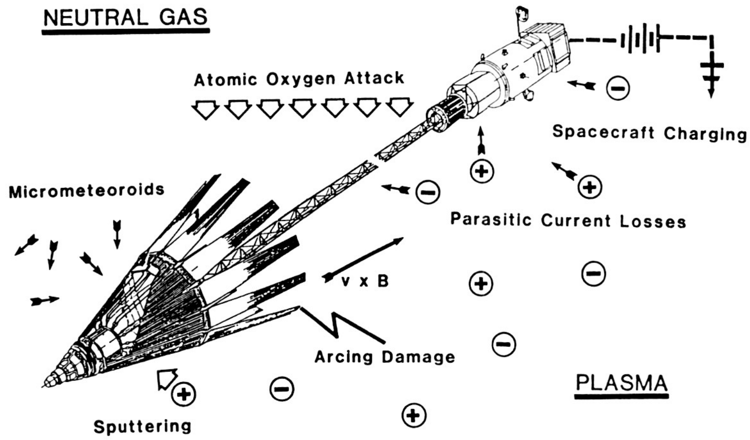
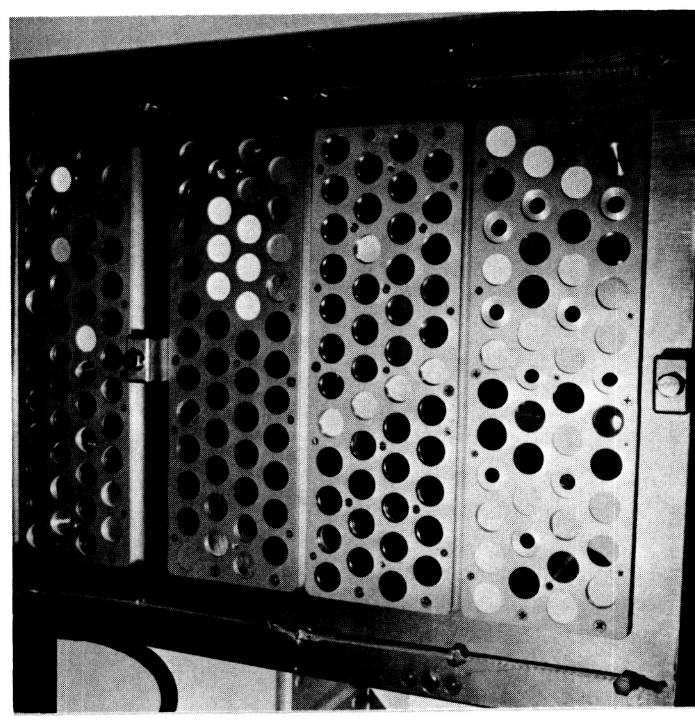


FIGURE 17. - SP-100 ADVANCED TECHNOLOGY SPACECRAFTR ENVIRONMENTAL EFFECTS.

EOIM-3 FLIGHT EXPERIMENT PLAN

- RAM EXPOSURE IN SHUTTLE PAYLOAD BAY
- 120 NM ORBIT, 40 HR EXPOSURE
- REFRACTORY MATERIALS, RADIATOR COATINGS, METALS AND POLYMERS (CABLE MATERIALS) TO BE TESTED
- 22 SAMPLES AT 60 ^{0}C, 22 AT 200 ^{0}C
- PRE- AND POST-FLIGHT TESTING INCLUDES:
  - MASS LOSS
  - SURFACE ANALYSIS
  - OPTICAL PROPERTIES
- IN-HOUSE EFFORT, IN COOPERATION WITH JSC, GE, A.D. LITTLE, CWRU

STATUS: SAMPLES READY, SOME IN GROUND TESTS, FLIGHT DELAYED UNTIL JANUARY 1991



PREVIOUS LeRC FLIGHT EXPERIMENT STS-8

FIGURE 18. - ATOMIC OXYGEN EFFECTS SPACE FLIGHT EXPERIMENT.

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15. Supplementary Notes

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16. Abstract

The SP-100 program was established in 1983 by DOD, DOE, and NASA as a joint program to develop the technology necessary for space nuclear power systems for military and civil application. During FY86 and 87, the NASA SP-100 Advanced Technology Program was devised to maintain the momentum of promising technology advancement efforts started during Phase I of SP-100 and to strengthen, in key areas, the chances for successful development and growth capability of space nuclear reactor power systems for future space applications. In FY88, the Advanced Technology Program was incorporated into NASA's new Civil Space Technology Initiative (CSTI). The CSTI Program was established to provide the foundation for technology development in automation and robotics, information, propulsion, and power. The CSTI High Capacity Power Program builds on the technology efforts of the SP-100 program, incorporates the previous NASA SP-100 Advanced Technology project, and provides a bridge to NASA Project Pathfinder. The elements of CSTI High Capacity Power development include Conversion Systems, Thermal Management, Power Management, System Diagnostics, and Environmental Interactions. Technology advancement in all areas, including materials, is required to assure the high reliability and 7 to 10 year lifetime demanded for future space nuclear power systems. The overall program will develop and demonstrate the technology base required to provide a wide range of modular power systems as well as allowing mission independence from solar and orbital attitude requirements. Several recent advancements in CSTI High Capacity power development will be discussed.

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